NRAP Open-Source Integrated Assessment Model and Relevant Application

NRAP Phase II Tools and Workflows

at the 2021 GWPC Annual Forum

Sept. 29, 2021

NRAP
National Risk Assessment Partnership

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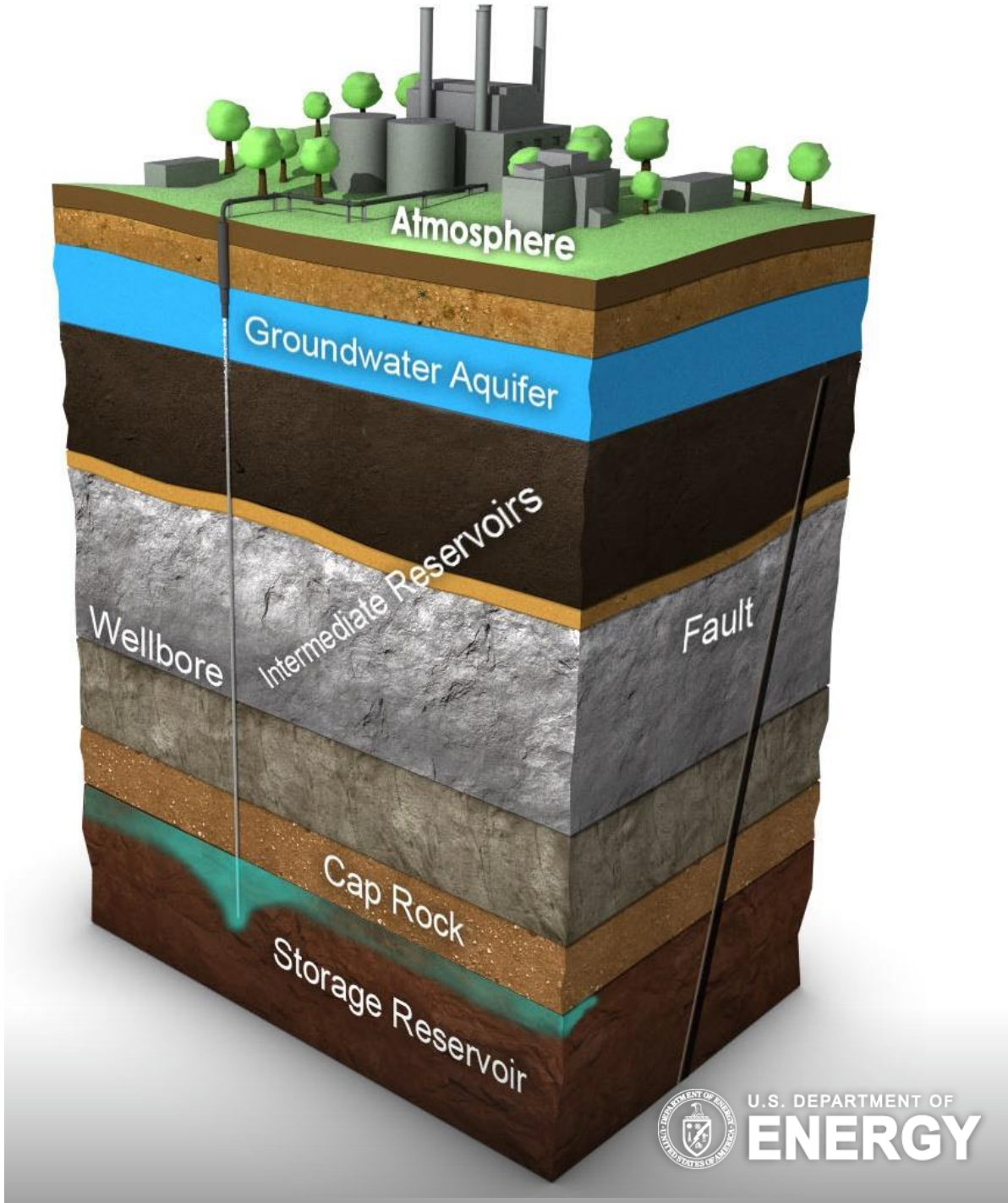

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Author

Veronika Vasylkivska

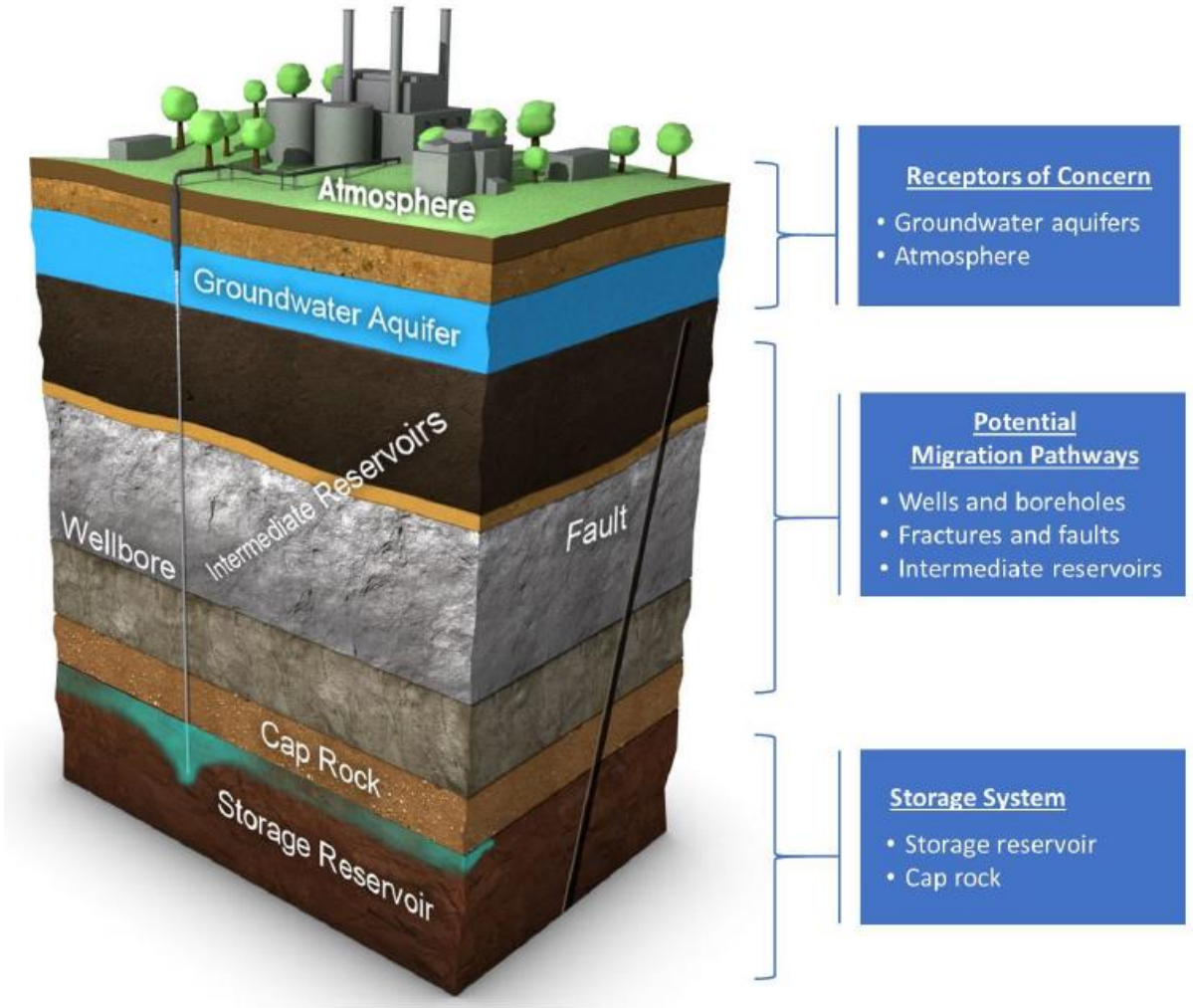
National Energy Technology Laboratory

NETL Support Contractor

Outline

- Introduction to NRAP-Open-IAM
- Core Functionality
- Applications
- Summary and References

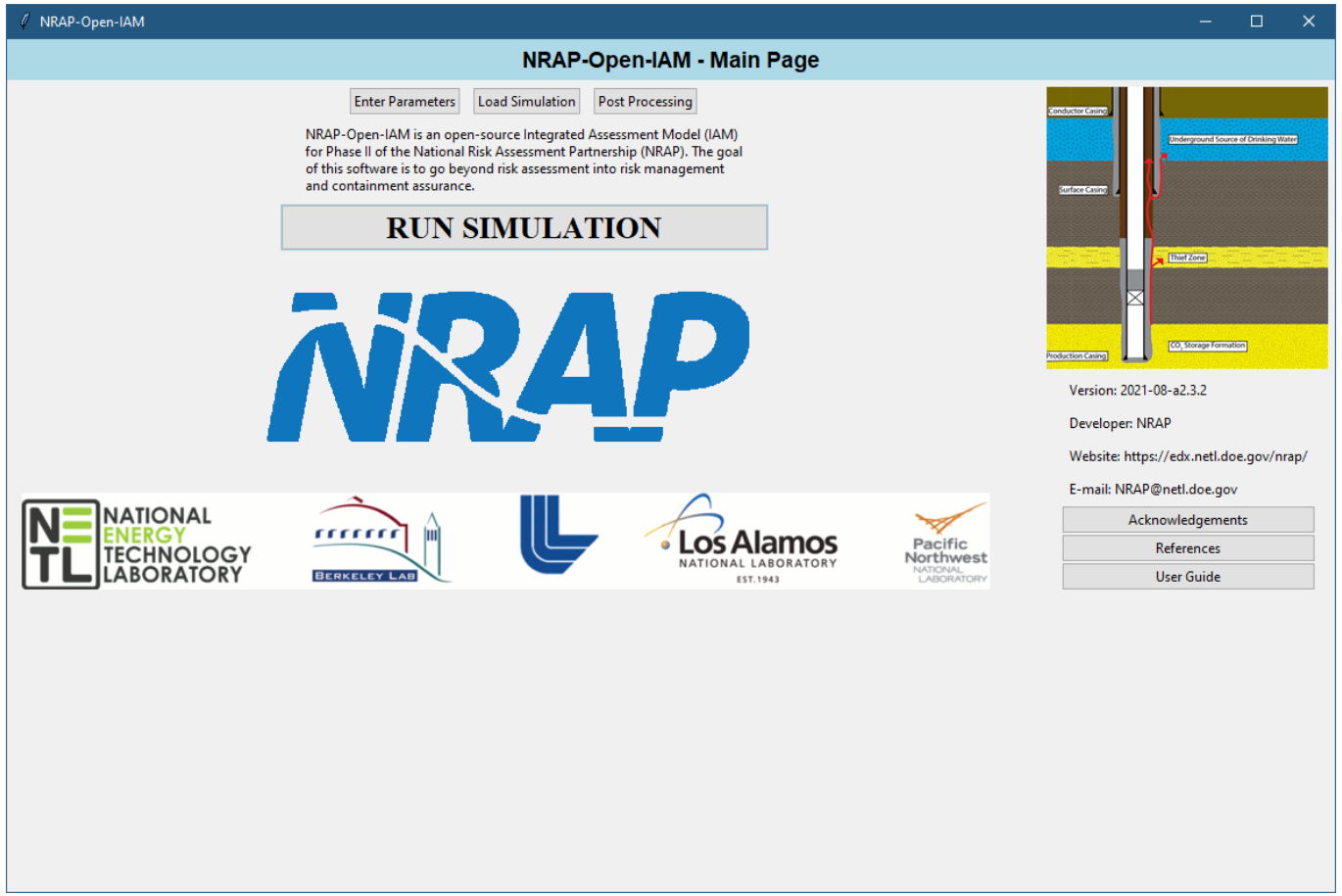
NRAP's Integrated Assessment Modeling Approach



A geological carbon storage (GCS) system is divided into component models representing the key elements of the operation:

- geologic stratigraphy
- storage reservoir
- potential leakage pathway(s)
- receptor(s) (e.g., groundwater aquifer, or the atmosphere)

NRAP-Open-IAM

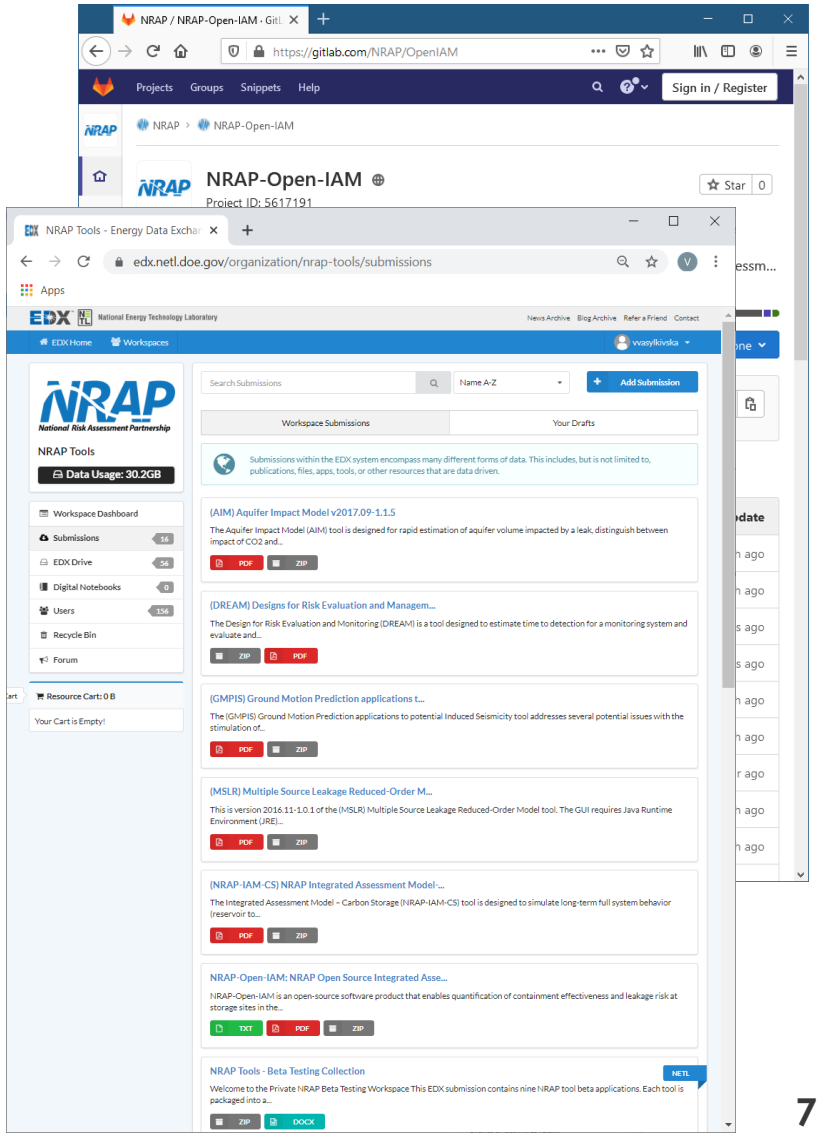


- Physics in each component is simulated with reduced order models (ROMs)
- ROMs are used to reduce computational times
- Each component can be analyzed individually (as in stand-alone tools)

- NRAP-Open-IAM *is not intended to replace existing reservoir simulators*
- Workflows and design can be adapted for different sites, but the tool *is not a catch-all for all GCS sites*

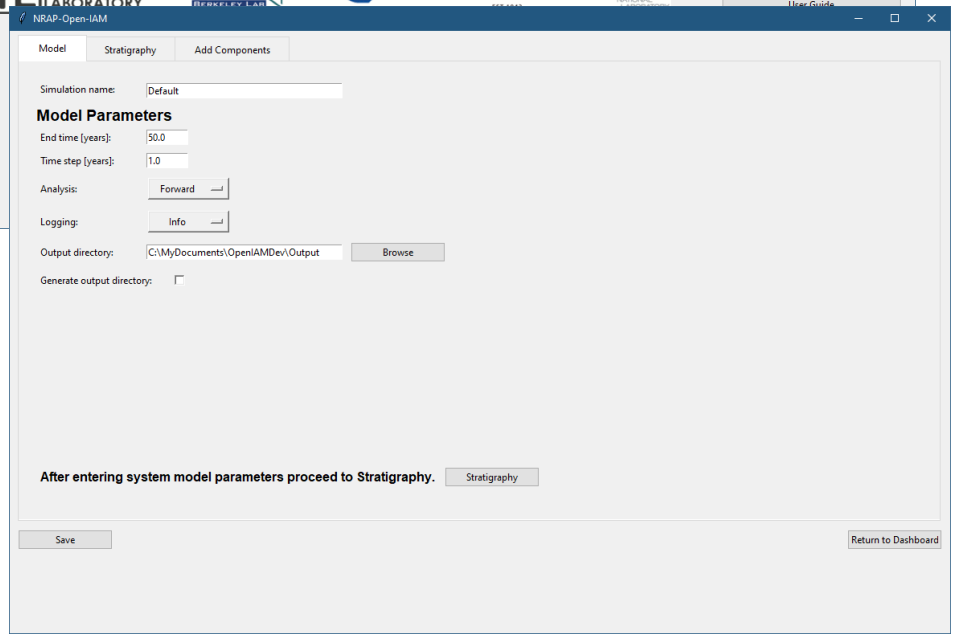
Source Code and Data Sets

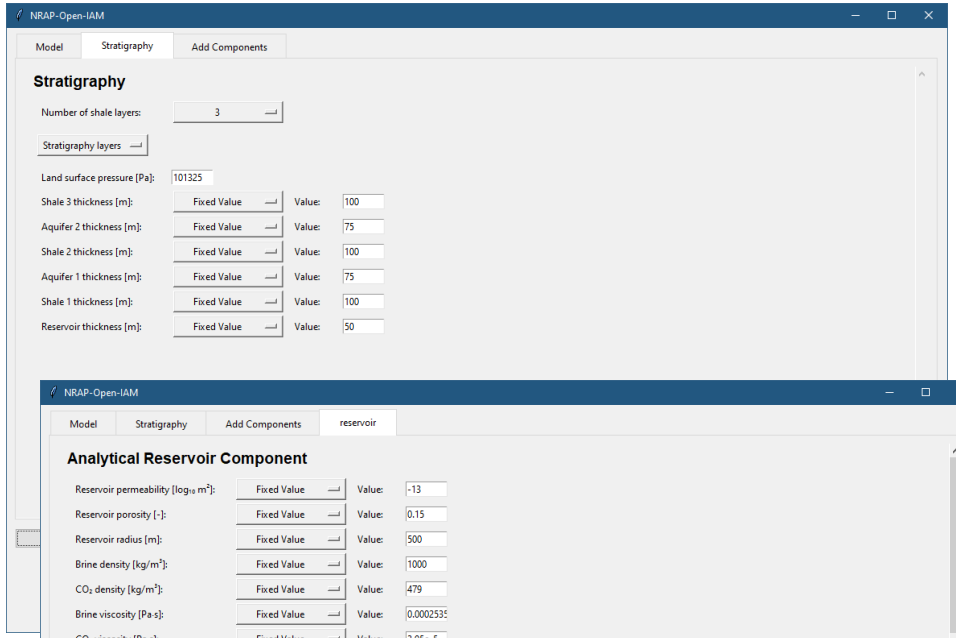
- Latest release: August 2021
- Source code (in Python)
  - on EDX: https://edx.netl.doe.gov/dataset/nrap-open-source-iam
  - on GitLab: https://gitlab.com/NRAP/OpenIAM
- Data
  - on EDX:
    - https://edx.netl.doe.gov/dataset/a3674794-c093-48b6-a097-b4fbeff7dd0c/resource/023f5fef-a581-4b42-887d-55d6e73dbd89
    - https://edx.netl.doe.gov/dataset/a3674794-c093-48b6-a097-b4fbeff7dd0c/resource/4d203e70-99ce-44fd-8e76-8594f736ccaf
    - https://edx.netl.doe.gov/dataset/futuregen-2-0-1008-simulation-reservoir-lookup-table
  - on GitLab: https://gitlab.com/NRAP/Kimberlina_data

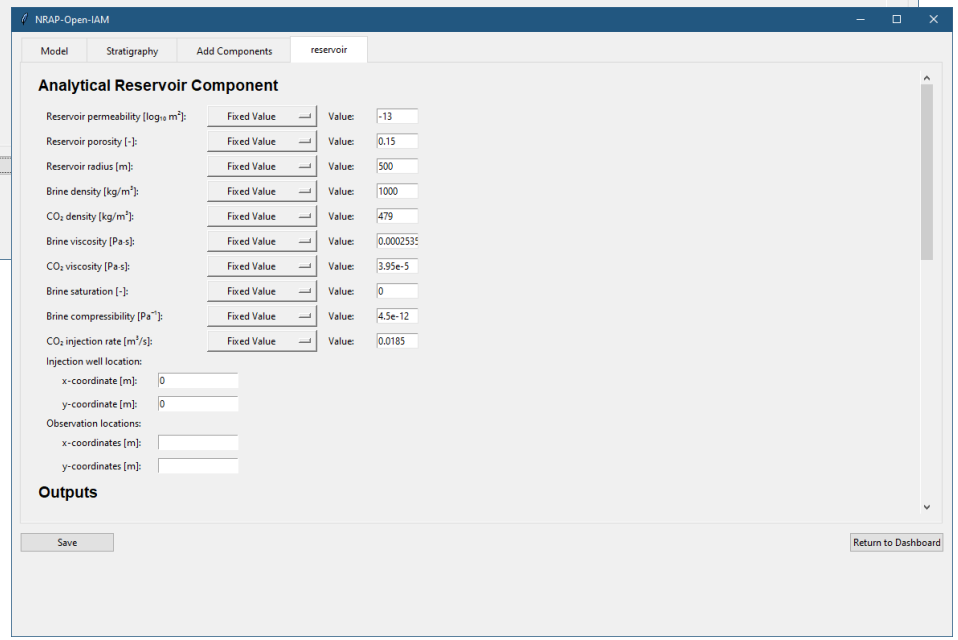


Components

Release version: 2021-08-a2.4.0







- **Reservoir**
  - Analytical reservoir
  - Lookup table reservoir
- **Wellbore**
  - Multisegmented wellbore
  - Cemented wellbore
  - Open wellbore
- **Aquifer/atmosphere**
  - Carbonate aquifer
  - Deep alluvium aquifer
  - FutureGen2 aquifer
  - FutureGen2 AZMI
  - Atmospheric ROM
- **Generalized flow rate**
- **Plume Stability Analysis**
- ***Seal Horizon***
- ***Fault Flow***
- ***Chemical Well Sealing***

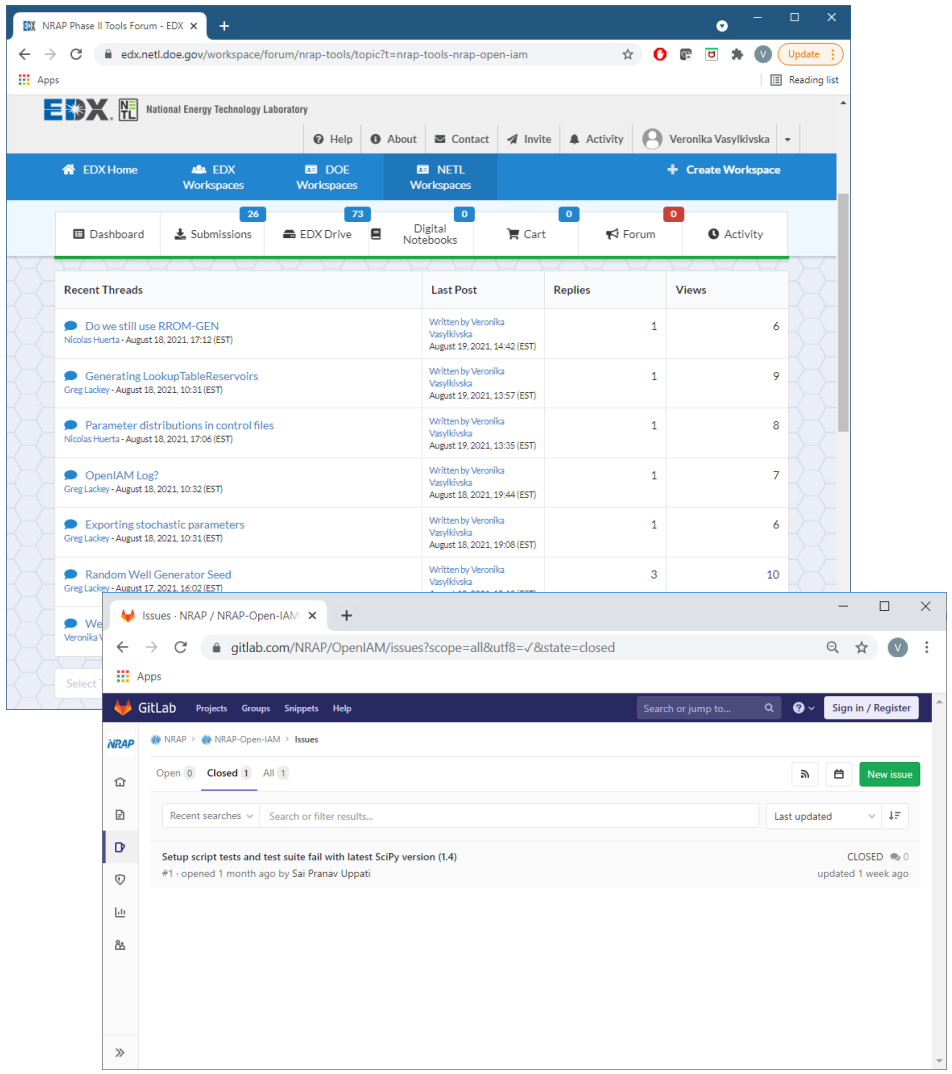
NRAP Application Catalog

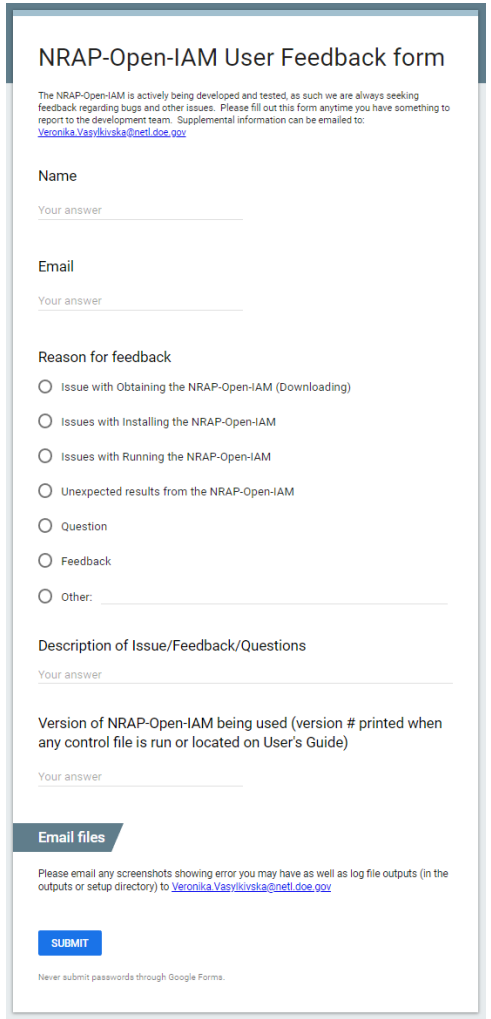
https://edx.netl.doe.gov/nrap/application-catalog/

Application focus	Study
Area of review	Probabilistic Risk-based AoR Determination at FutureGen 2.0 Site
Monitoring design, post-injection site care	Coupling of NRAP-Open-IAM and DREAM for Risk-based Monitoring Design and PISC Period Determination at the FutureGen 2.0 site
Corrective actions, monitoring design, post-injection site care, well leakage	Application of NRAP-Open-IAM to the Kimberlina Site
Aquifer impacts, well leakage	Application of the Aquifer Impact Model to the Decatur Site
Initial risk assessment, well leakage	Application of NRAP-Open-IAM to Illinois Christian (Macon) County CarbonSAFE
State of stress, induced seismicity, well leakage	Application of NRAP-Open-IAM and SOSAT at existing oil fields in IMSCS CarbonSAFE, Sleepy Hollow Field

Questions/Comments/Feedback

- Forum on EDX
  https://edx.netl.doe.gov/organization/forum/nrap-tools/topic?t=nrap-tools-nrap-open-iam
- Issues on GitLab
  https://gitlab.com/NRAP/OpenIAM/issues
- Google User Feedback Form
  https://docs.google.com/forms/d/e/1FAIpQLSed5mcX0OBx1dLNmYGbmS4Vfc0mdOLapIzFqw-6vHoho9B19A/viewform

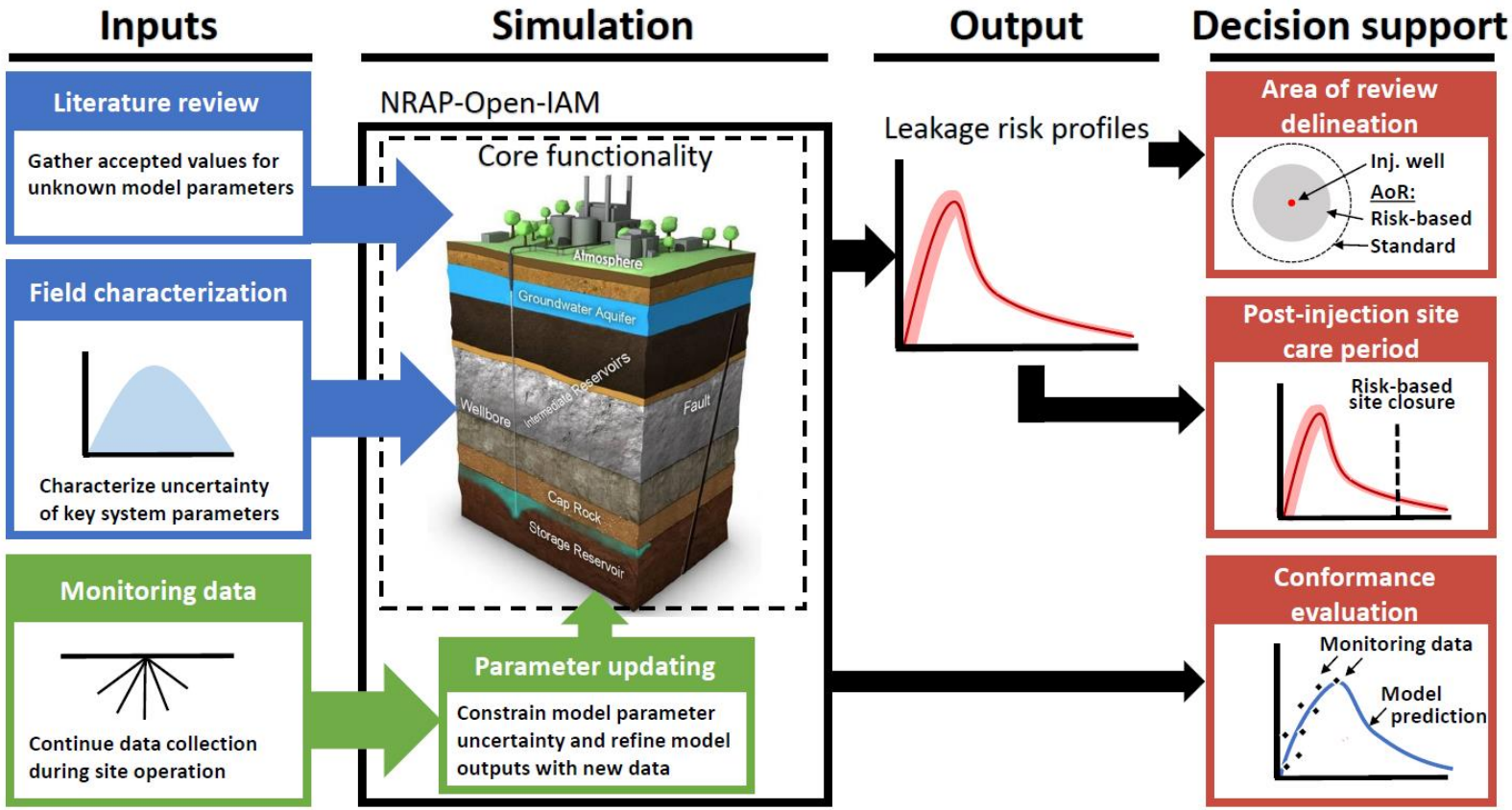




Core Functionality

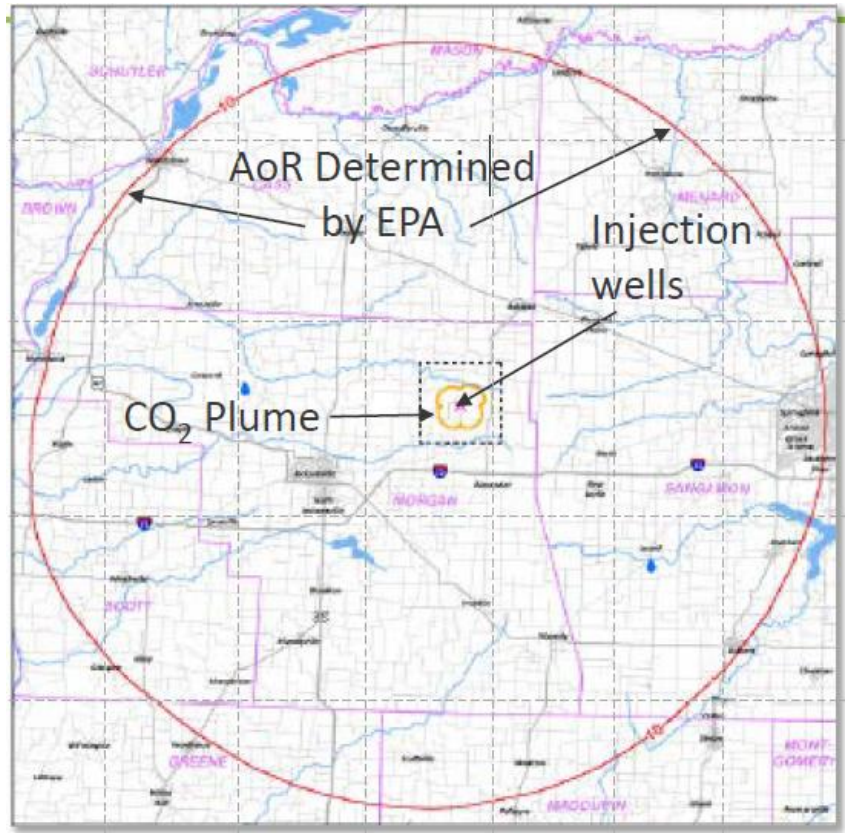
Decision-support applications

- AoR evaluation
- conformance/concordance metrics
- pressure and CO_2 saturation plume stability analysis
- containment effectiveness
- informing monitoring design
- assess model concordance to measured field data
- evaluation of mitigation alternatives
- risk analysis
- uncertainty reduction
- closure decision support



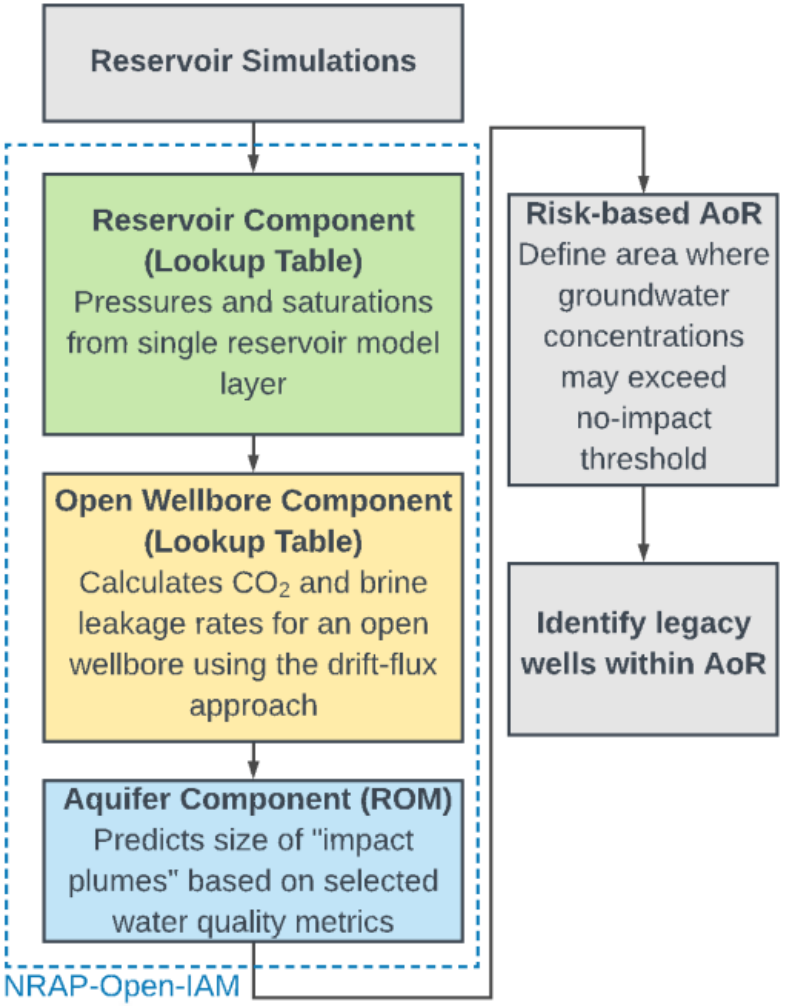
Application 1: FutureGen 2.0 - Evaluating Risk-Based Area of Review

- AoR is the area surrounding the injection project where groundwater resources may be endangered by the activity
- EPA requires operators to determine the Area of Review (AoR) based on the separate-phase CO_2 plume/pressure evolution predictions from physics-based computational modeling
- AoR is delineated by the maximum extent of CO_2 plume and pressure front over the lifetime of the project to account for risks associated with both CO_2 and/or brine leakage into the overlying groundwater aquifer



Probabilistic Risk-Based AoR: Setup

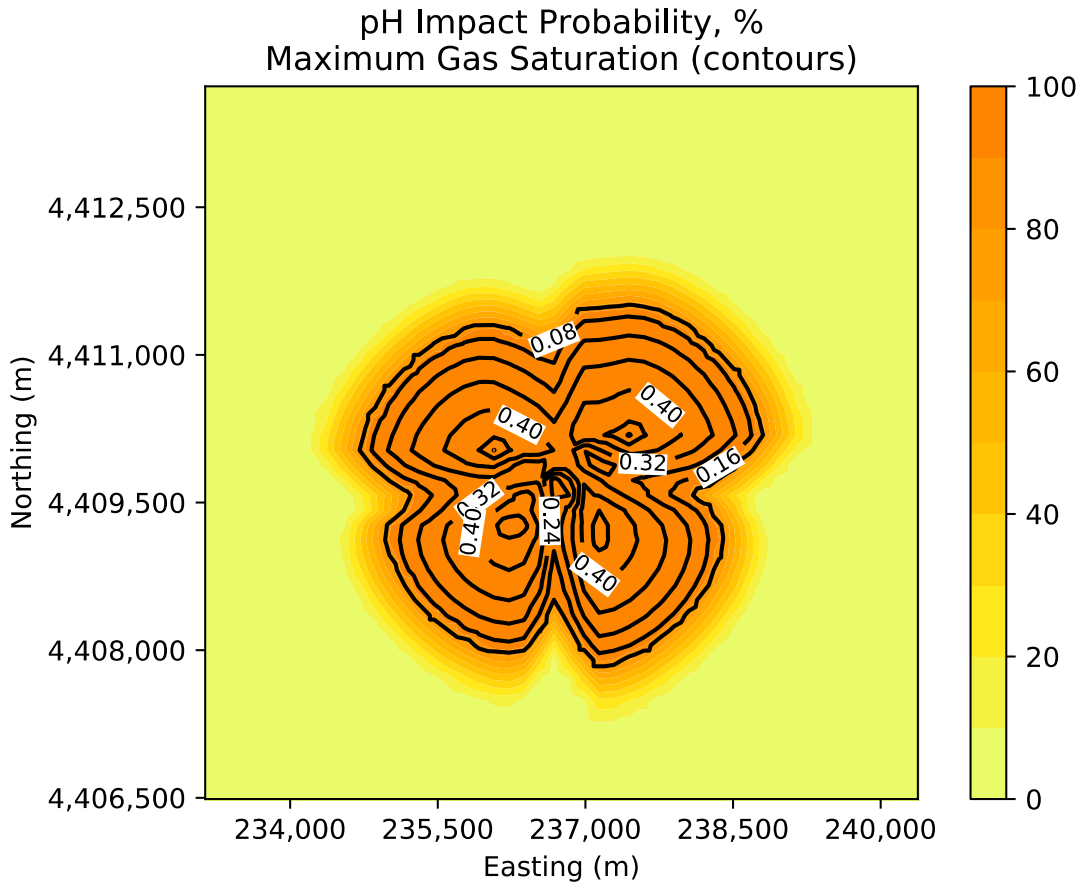
- Mt. Simon: Over-pressurized reservoir with respect to the lowermost USDW (STOMP, *reservoir component*)
- Pressure front and AoR determined by EPA is based on 10 psi critical pressure.
- Determination of project risk associated with leakage into the aquifer:
  - use of physics-based multiphase modeling for plume and pressure predictions
  - wellbore leakage assessment (*open wellbore component*)
  - evaluation of aquifer impact (*aquifer component*)



Reference: *Bacon et al., 2020. Probabilistic Risk-based Area of Review (AoR) Determination for a Deep-Saline Carbon Storage Site, IJGGC.*

Probabilistic Risk-Based AoR: Calculations

- Base AoR delineation on impact to the aquifer if a well is placed at a particular location
- Loop through all X,Y locations in reservoir model layer:
  - find pressure and saturation in reservoir
  - use wellbore component to determine CO_2 and brine leakage rates to aquifer
  - calculate pH and TDS impact volumes vs. time and location
- Map maximum pH and TDS impact volumes on X,Y grid for each realization
- Calculate probability of aquifer impact for each grid location



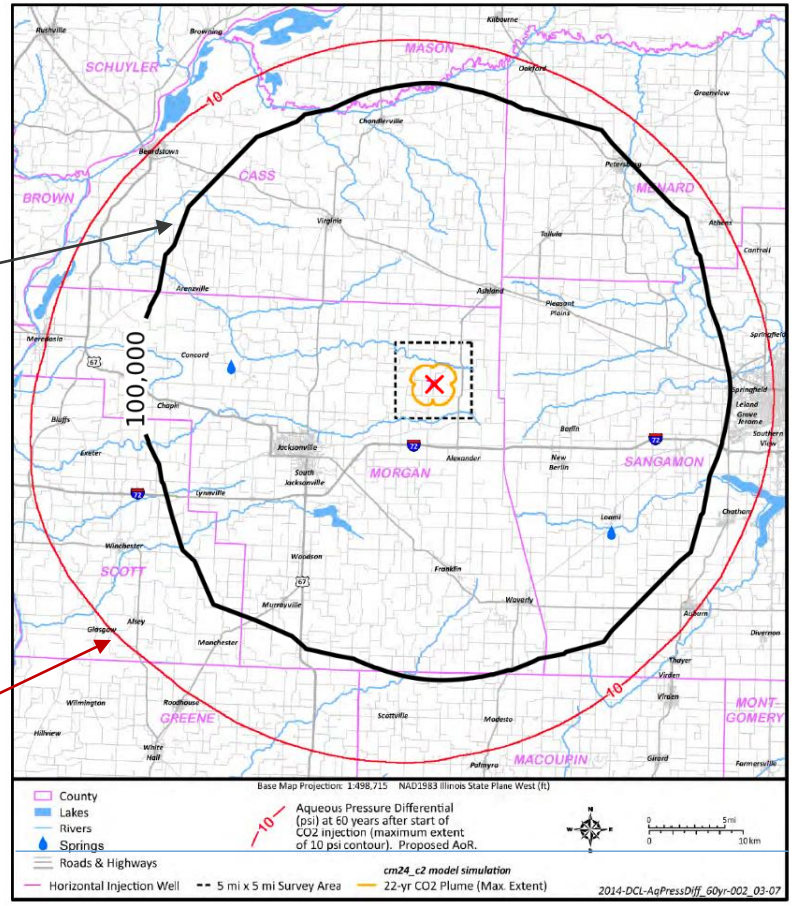
Conclusion: AoR Comparison

- Area of aquifer impact based on probability of change in aquifer pH is equivalent to plume footprint
- Area of aquifer impact based on probability of change in aquifer total dissolved solids (TDS) is
  - smaller than AoR determined with critical pressure of 10 psi
  - much larger than plume footprint
- Probabilistic risk-based analysis yields smaller AoR

Risk-Based AoR (100,000 Pa / 14.5 psi (black)
Class VI Permit AoR 68,974 Pa / 10 psi (red)

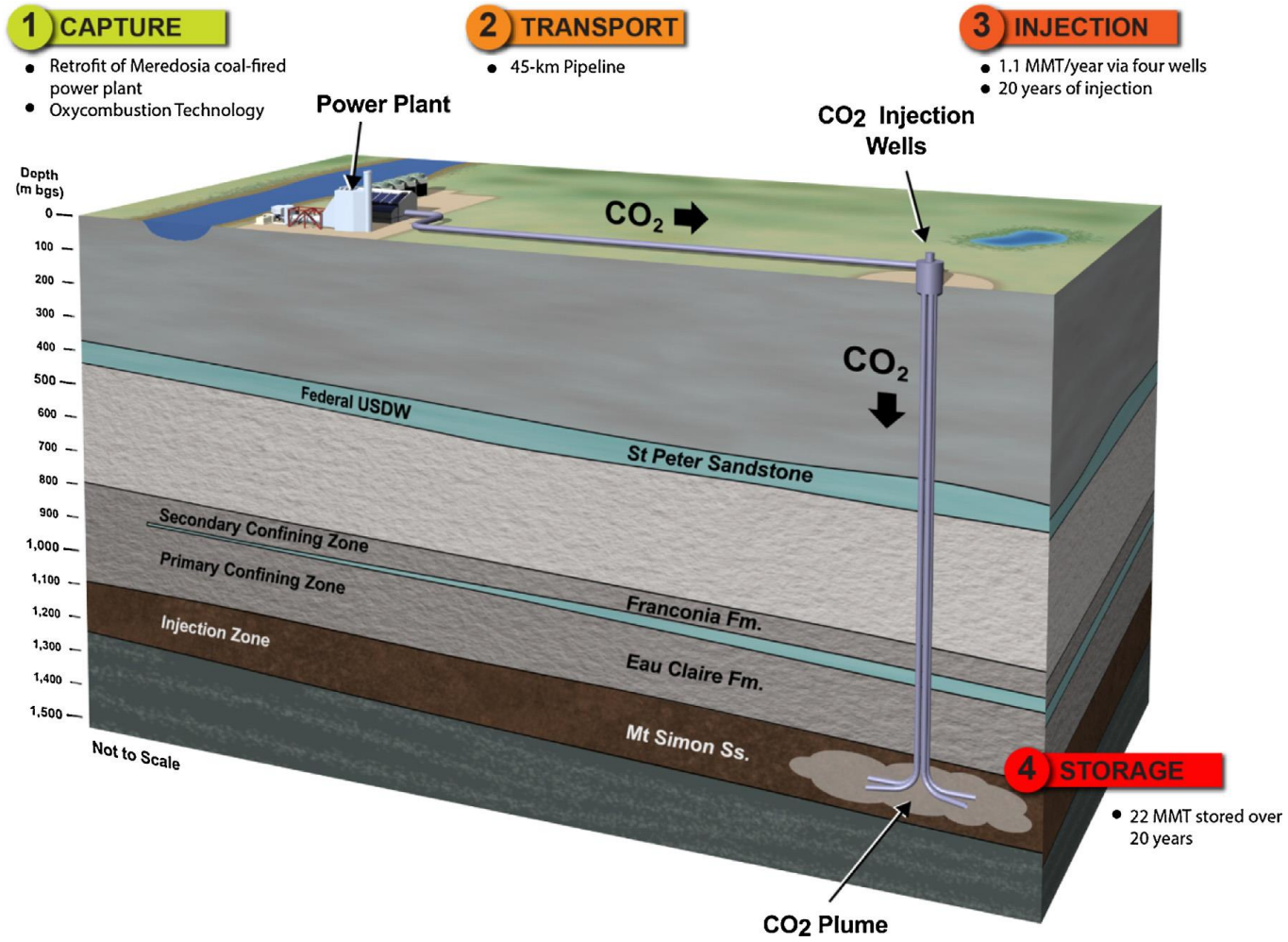
Risk-based AoR

AoR determined by EPA using 10 psi critical pressure



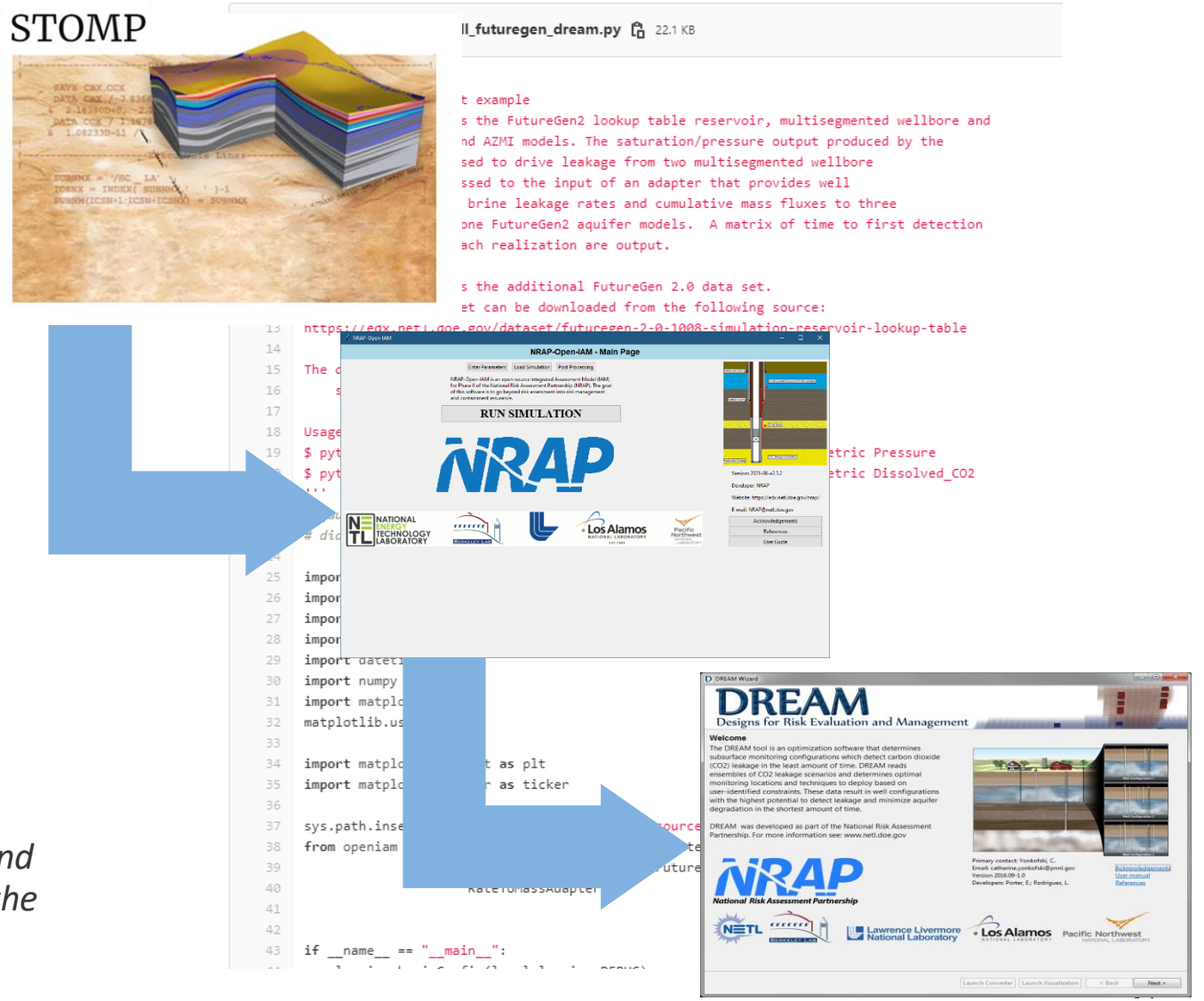
Application 2: FutureGen 2.0 - Monitoring Design and PISC Period Determination

- U.S. EPA recommended the use of the default 50-year PISC period for the UIC Class VI permit application
- EPA's Class VI regulations require demonstration of non-endangerment before site can be closed
- FutureGen 2.0 projected reservoir performance
  - CO_2 plume is to stabilize 2 years after injection stops
  - Reservoir pressure is to decline rapidly post-injection



Approach

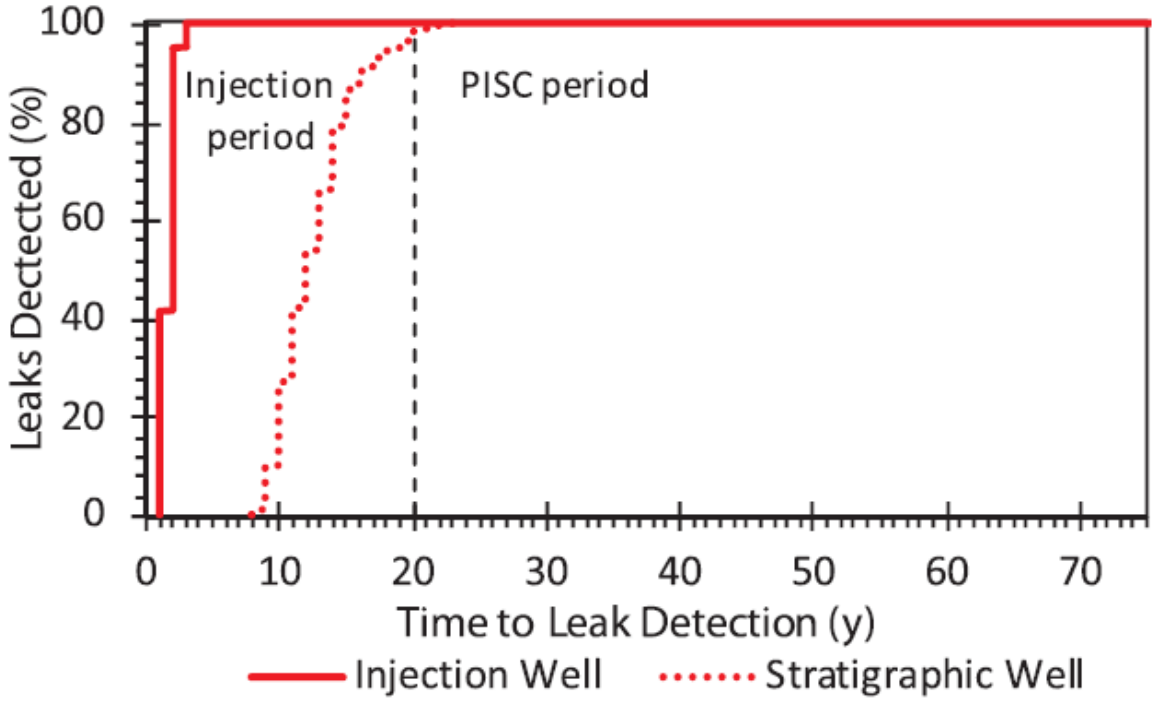
- STOMP-CO2: pressure and CO saturation for reservoir component
- STOMP-CO2E-R: simulations for FutureGen 2.0 aquifer component
- NRAP-Open-IAM
  - analysis of leakage risk evolution over time to overlying USDW
  - time-to-detection (TTD) files
- DREAM: design of an adaptive monitoring network for the site



Reference: *Bacon et al., 2019. Risk-based post injection site care and monitoring for commercial-scale carbon storage: Reevaluation of the FutureGen 2.0 site using NRAP-Open-IAM and DREAM IJGGC.*

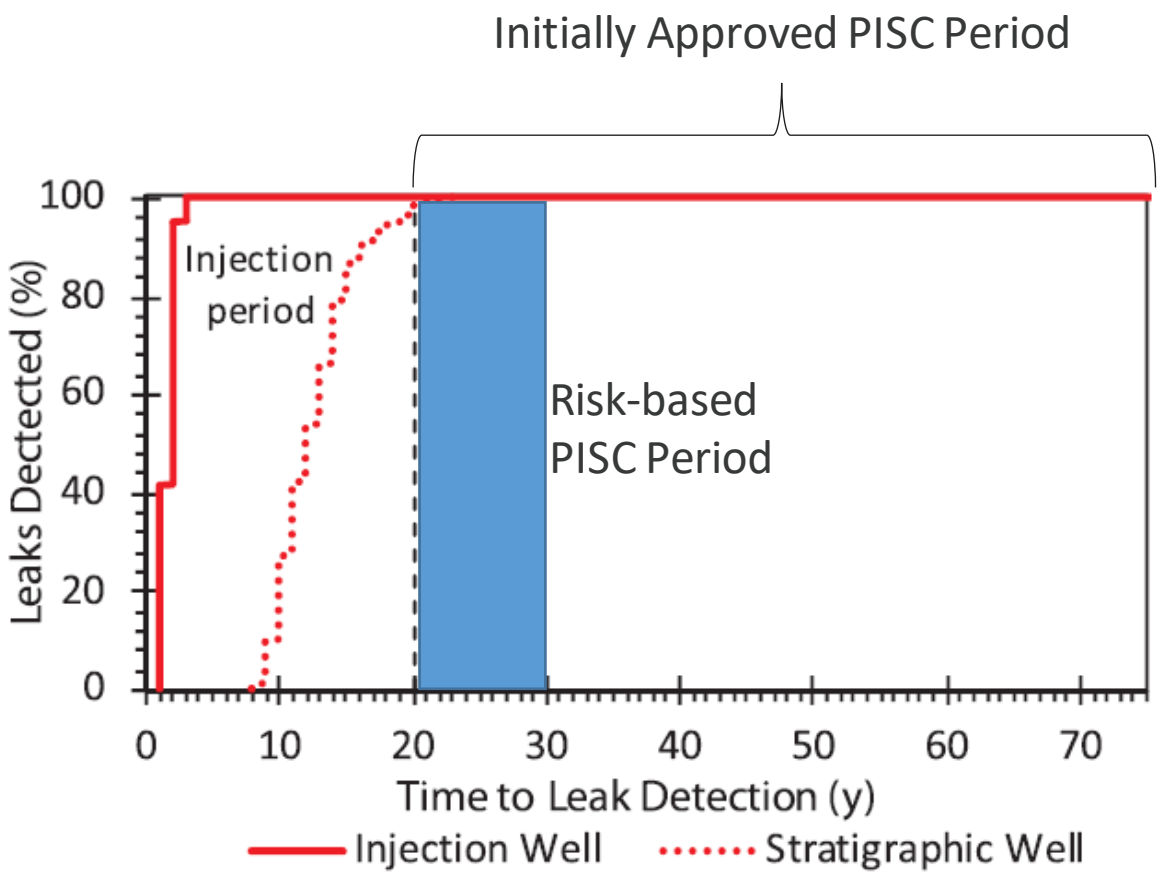
Monitoring Design

- Original monitoring plan: two AZMI wells and one USDW well
- DREAM optimized monitoring plan: 1 AZMI and 1 USDW monitoring well
- Over $10M in avoided costs for installation, sampling, and decommissioning of the second AZMI well
- Net risk reduction at the site: 1 fewer conduit for leakage from the deep subsurface to the overlying USDW



PISC Period

- NRAP-Open-IAM can be used to define a risk-based PISC period for the site
- Maximum simulated leakage rates of brine were small and could be detected during the injection phase
- Majority of risk of endangerment to USDWs decreases within the first 5 years after CO_2 injection ends
- Results support a net PISC period reduction of 40 years and an operational cost reduction in excess of $50M

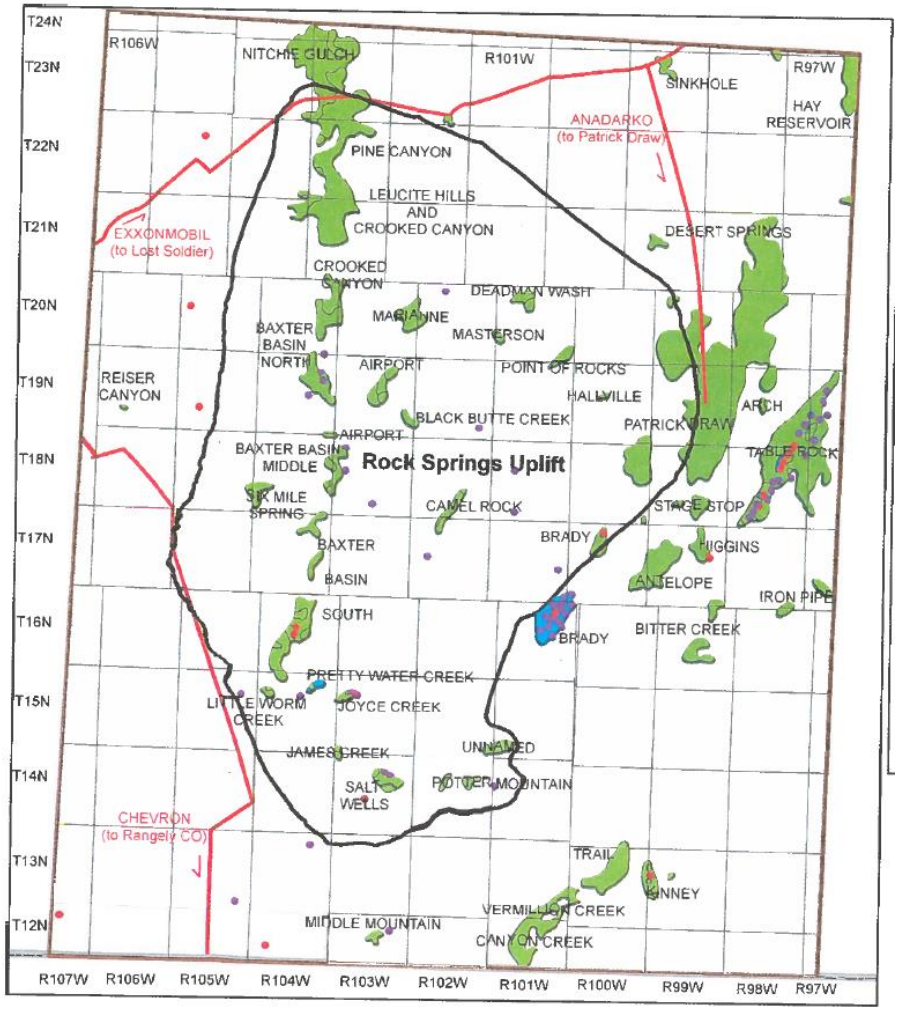


Application 3: Rock Springs Uplift – Conformance and Uncertainty Reduction

During a GCS project, operators need to determine that GCS operations are and will continue to perform within acceptable levels of risk and within the bounds of its permit and related legal requirements to establish conformance with appropriate regulatory criteria

Important consideration to build this confidence:

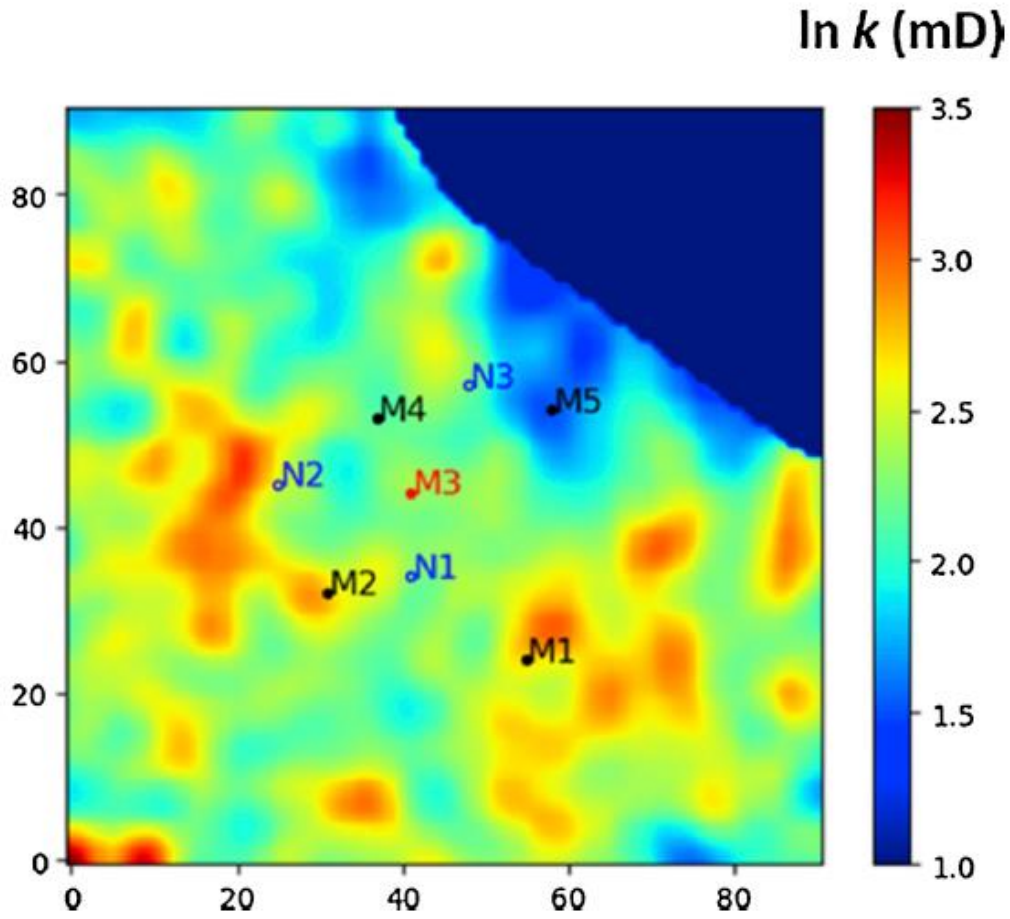
- pressure increases in the storage reservoir due to CO_2 injection are in concordance with previously forecasted behavior
- pressure forecasts updated based on available monitoring data conform with desired performance based on appropriate regulatory and engineering criteria



Reference: Surdam, R.C. and Jiao, Zunsheng. The Rock Springs Uplift. An outstanding geological CO2 sequestration site in southwest Wyoming. Wyoming State Geological Survey

Conformance Analysis Setup

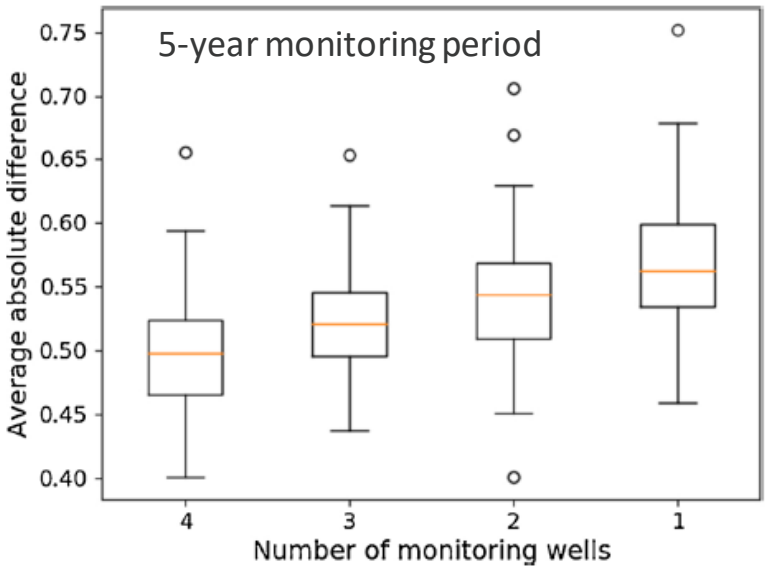
- System model (numerical simulator): FEHM
- Uncertainty model (e.g., probabilistic distribution): permeability field
- Concordance metric (e.g., RMSE)
- Performance metric (e.g., safe pressure threshold)
- Performance observations (e.g., monitoring well pressure)

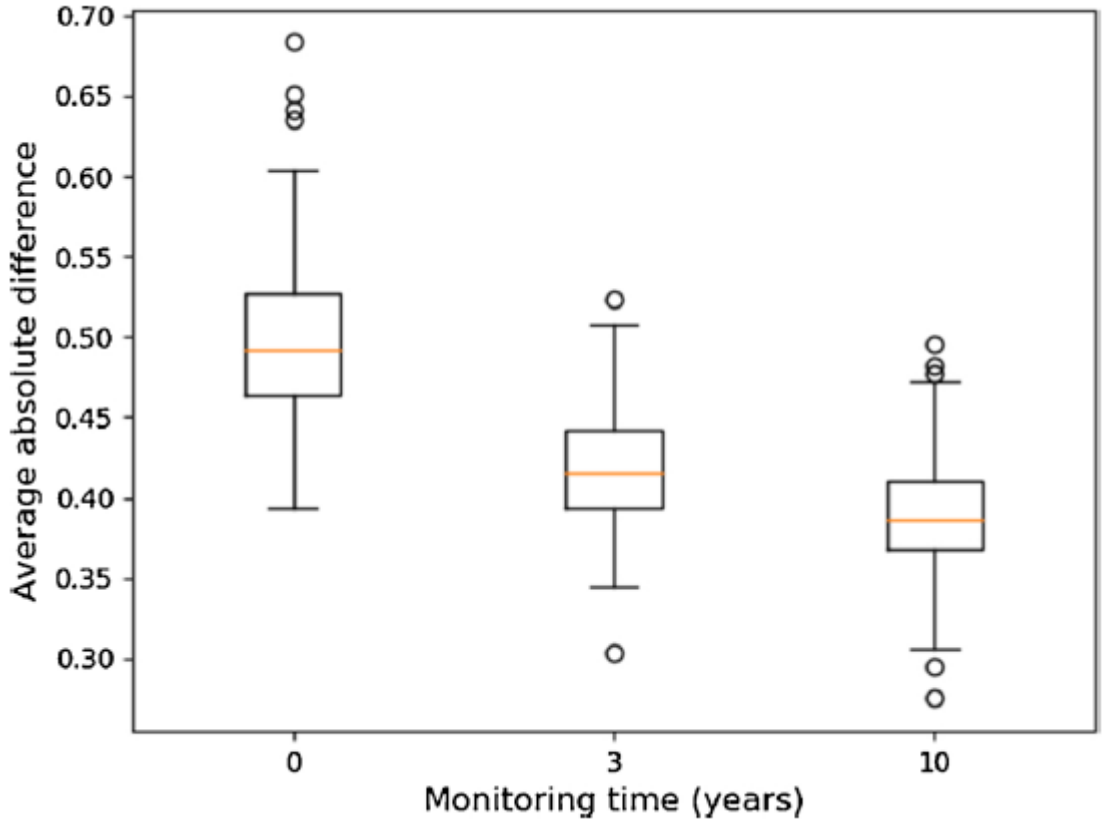


Reference: *Chen et al., 2019. Reducing uncertainty in geologic CO2 sequestration risk assessment by assimilating monitoring data. IJGGC.*

Data Assimilation

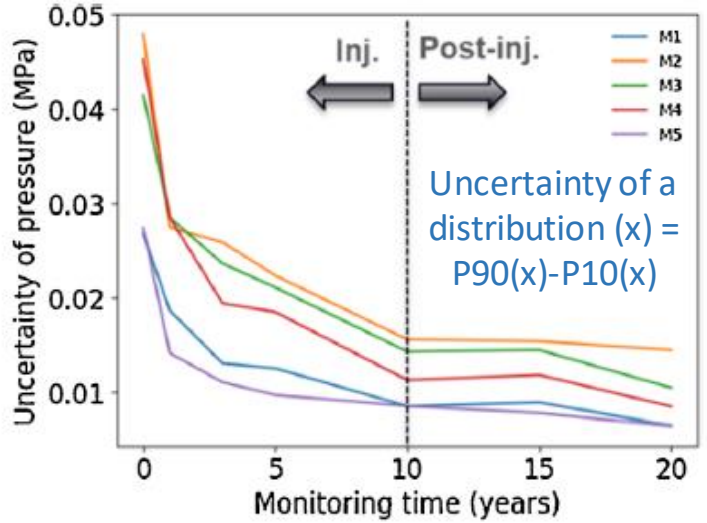
- Concordance improves and uncertainty is reduced as more data are obtained
- The extent of model improvement depends on the number of monitoring wells

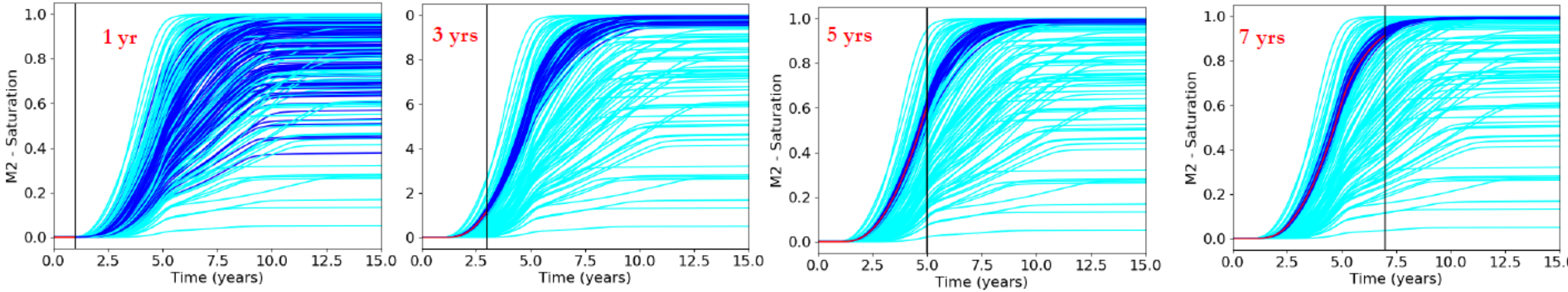




Conformance: Uncertainty Reduction

- Reduced uncertainty -> reduced risk -> increased confidence in conformance
- Assimilation of monitoring data can significantly reduce the uncertainties in predictions including during the post-injection period
- NRAP-Open-IAM can be used for quantification of uncertainty reduction in wellbore leakage rates and groundwater aquifer impact in legacy wells





Summary

- NRAP-Open-IAM team is developing new functionality for fit-for-purpose analyses that may be useful to support design and decision making at GCS sites
- These new capabilities can help
  - evaluate risk-based AoR
  - inform monitoring design
  - define risk-based PISC period
  - assess model concordance to measured field data
- Ongoing work seeks to field test and validate the underpinning methods and analytical capabilities to improve the existing NRAP-Open-IAM functionality

References

- Bacon et al., 2020, Probabilistic Risk-based Area of Review (AoR) Determination for a Deep-Saline Carbon Storage Site, IJGGC
- Bacon et al., 2019, Risk-based post injection site care and monitoring for commercial-scale carbon storage: Reevaluation of the FutureGen 2.0 site using NRAP-Open-IAM and DREAM, IJGGC
- Chen et al., 2020. Reducing uncertainty in geologic CO_2 sequestration risk assessment by assimilating monitoring data, IJGGC
- Harp et al., 2019. A metric for evaluating conformance robustness during geologic CO_2 sequestration operations, IJGGC
- Lackey et al., 2019. Managing Well Leakage at a GCS Site with many wells, IJGGC
- Vasylkivska et al., 2021. NRAP-Open-IAM: A Flexible Open-Source Integrated Assessment Model for Geologic Carbon Storage Risk Assessment and Management, EMS

Questions?

If you have questions about NRAP-Open-IAM that we did not address today, please post your question on the forum page* for all the user community to benefit from the answer.

***Forum on EDX:**
https://edx.netl.doe.gov/organization/forum/nrap-tools/topic?t=nrap-tools-nrap-open-iam

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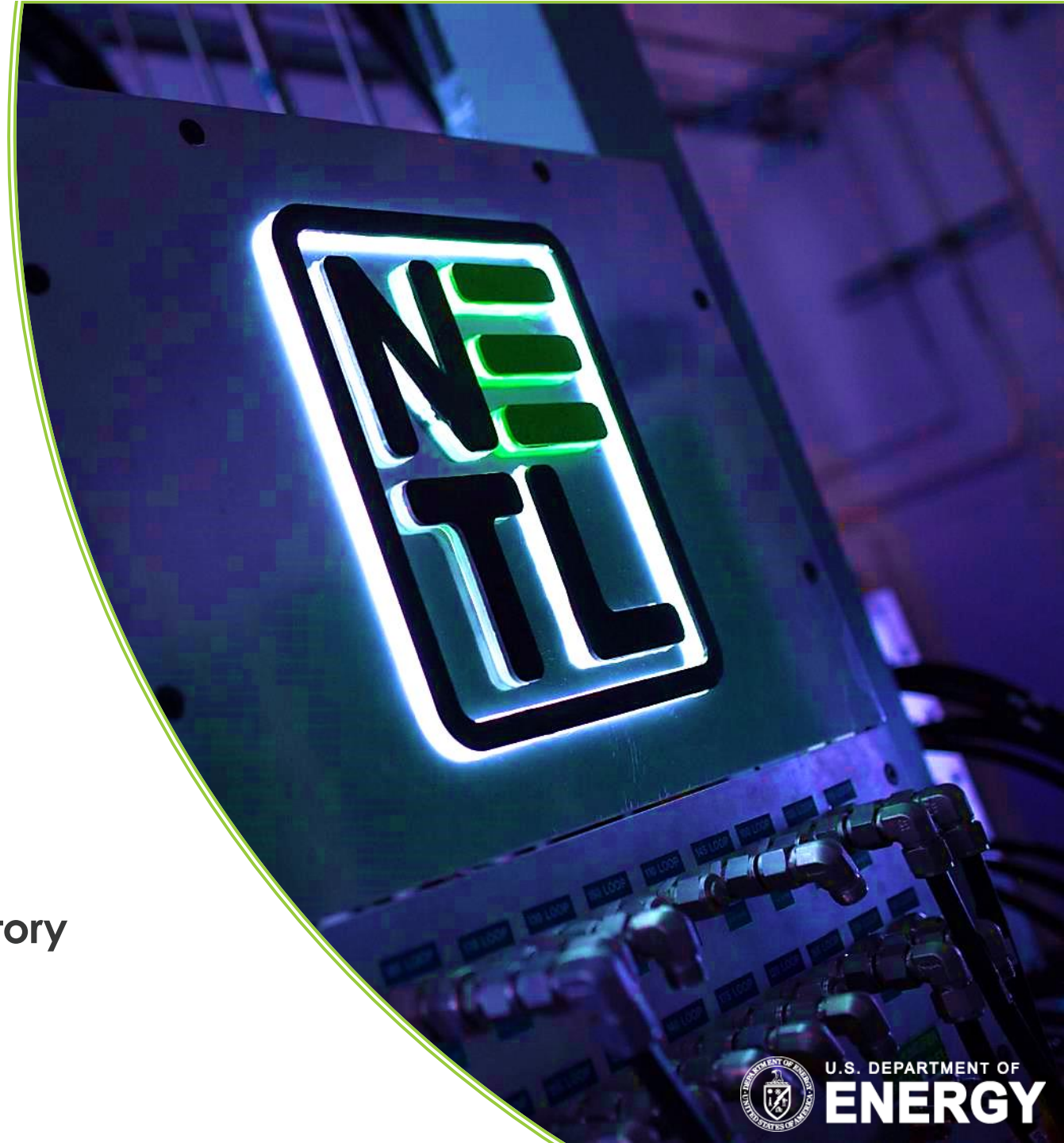

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